Forest Vulnerability to Climate Change

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Climate change has caused vulnerability not only to the forest ecosystem but also to forest-dependent communities. Therefore, its management is essential to increase forest ecosystem services and reduce vulnerability to climate change using an integrated approach.

climate change forest management forest vulnerability

1. Introduction

Climate change continues to be the primary stressor of the planet and is projected to be a great challenge for the 21st century in view of high emission conditions. Increased fossil fuel combustion, increased use of fertilizers, deforestation and land use/land cover change have driven up the concentration of greenhouse gases in the atmosphere. All these processes have resulted in the alteration of the earth's climate [1]. Forest acts as an essential resource for regulating the earth's climate, sequestering a significant amount of carbon from the atmosphere and maintaining ecological stability [2][3][4]. This important resource is constantly degraded due to anthropogenic activities and climate change. Climate change has adversely affected the environment's state at spatial scales [5][6][7]. The Intergovernmental Panel on Climate Change (IPCC) has reported that if the global temperature continues to increase at the present rate, it may increase by 1.5 °C between 2030 and 2052, altering the frequency and severity of natural disturbances and having potentially profound impacts on forest resources and species composition [8]. The recent IPCC (2022) report projected the risk for the near-term (2021–2040), mid-term (2041–2060) and long-term (2081–2060) at different levels and 1.5 °C across multiple decades [9].

Climate change has had several effects on forests and will likely lead to a rise in temperature in the near future. Indigenous communities living in forest regions are particularly vulnerable to climate change as they lack the sufficient adaptation capacity to cope with climate variation and extremes, and have limited access to alternative sources of income [10][11]. Hence, monitoring and assessing the climate change impact on forests is a prerequisite in lessening its effects and making suitable adaptation strategies. The US Government conducted the first global assessment in the earlier part of this century [12]. In addition, several international organizations or institutions, such as the Food and Agriculture Organization (FAO), UN Framework Convention on Climate Change (UNFCCC), Convention on Biological Diversity, and World Wildlife Fund (WWF) are aiming to combat climate change and its effects on forest dynamics [13]. After UNFCCC concern, a policy was laid for reducing emissions arising due to deforestation and degradation. The convention also stressed the sustainable utilization and management of forest and increased forests' carbon stocks [12].

Several approaches were utilized to assess and monitor the health of the forest, such as forest fragmentation [10][14][15][16][17][18][19], household dependency [10][20][21][22][23][24] and forest susceptibility [25][26][27][28]. Previous research has examined the climate change impact on forest [18][29][30][31][32][33][34][35][36][37][38][39][40][41]. The focus of study has now shifted from a general impact assessment to a vulnerability assessment involving all its components (exposure, sensitivity and adaption). Researchers and practitioners are now highly interested in understanding the dynamics of forest vulnerability assessment [42][43][44]. The IPCC has defined vulnerability as the susceptibility to adverse effects. It involves three essential components, viz. exposure, sensitivity and adaptation [45]. Two main approaches to vulnerability assessment, i.e., contextual and outcome have been distinguished. The contextual approach is applied to assess the current impacts, while the outcome approach is utilized to assess future impacts. The contextual approach is participatory, where social and ecological impacts are assessed using qualitative data. The outcome approach assesses biophysical impacts by employing modelling [46].

Forests differ significantly around the world. The regional disparities in climatic effects and adaptation capability significantly impact forest vulnerability [47]. Approximately 240 million people live in tropical forests in developing nations, including some of the world's poorest and most marginalized people who rely on the forest for their livelihood [48]. Local-scale studies allow a deep understanding of the system and dynamics at a local level and are helpful in deciding priorities for vulnerability reduction. Forest vulnerability assessment at the local level primarily reveals communities' actual responses to climate impacts, thus, employing their knowledge and abilities for developing and implementing appropriate strategies is highly valued [49]. The local level approach helps to identify and assess climatic threats and their implications on community livelihoods. This assessment, however, necessitates a comprehensive understanding of forest dynamics and how numerous structural changes influence them. As a result, a participatory or "bottom-up" method must be adopted for local-level vulnerability assessments. Furthermore, local scale studies directly link monitoring and broader notions of sustainable forest management, such as biodiversity protection and livelihood assistance. They also enhances local people's ability to care for their immediate environment by raising awareness and knowledge about the present state of the forests and surrounding regions [50]. A plethora of methods, approaches and models have been utilized in earlier studies to evaluate forest vulnerability to climate change. However, these studies mainly emphasized the forest ecosystem vulnerability to climate change on the global scale [51][52][53]. Some studies have also attempted to examine the vulnerability of forest-dependent communities to climate change [54][55][56].

2. Climate Change Impact and Forest Vulnerability

The concept of vulnerability has its origin in natural hazard studies [57] and has been defined as an outcome of exposure, sensitivity and adaptive capacity. Over time, vulnerability became a multi-dimensional topic among the scientific community. Forest exposure to climate change is a highly complex problem to be understood because current and future climate changes are affecting forest adaptability along with their dependent communities [58]. Climate change impact and forest vulnerability assessments have occupied an important place in recent scientific studies. Proxy measures, such as temperature variables or indicators which typically recognize critical processes to assess forest inherent vulnerability were used to reduce the implications [40][43]. Thus, the vulnerability assessment's structure must be revised to account for its multidimensionality in space and time [59]. Climate change has a major influence on forests globally and has been deliberated by several literatures. It affects the forestry habitat structure and plays a critical role in forest health conservation. However, the temperature is fluctuating worldwide. There were influential factors influencing forests, such as temperature, precipitation, relative humidity and photosynthesis-active radiation (PAR) [33]. The long seasonal extension has important implications for forestry growth and productivity. Climate change is predicted to affect forest disturbance frequency, and goods and services, according to their locations and habitats. Climate change has reduced the forest ecosystem's regulating capacity and created severe consequences for flora and fauna, particularly at the regional and local scale. Persistent forest loss has negatively affected communities' livelihoods and posed a significant challenge to the sustainability of the forest ecosystem. Many studies have touched upon the structure and function of the forest ecosystem, covering the distribution of species, fragmentation of forest, canopy density and habitat suitability using scientific models. However, the global community seems to be reaching a critical juncture, with recent commitments and initiatives, such as the Paris Agreement, Sustainable Development Goals (SDGs), and UN Strategic Plan for Forests 2017–2030 (UNSPF) contributing to a positive trajectory of progress. These organizations aid countries in overcoming these challenges by imparting policy advice, capacity building and technical support [13]. Sustainable forest management involves optimizing the benefits of forest resources to satisfy the needs of society by conserving and maintaining forest ecosystems for both present and future generations. Several studies on the influence of climate change on forest cover have found that shifting patterns of vegetation cover varied across areas due to spatiotemporal changes in climate change and eco-environmental factors [60]. It is also evident that changes in forest dynamics are not only due to climate change but are also accelerated by several anthropogenic disturbances [18]. Thus, ecological and inherent vulnerability assessments are significant for examining the exposure and sensitivity components.

Current forecasts of future temperature and rainfall changes cover a broad spectrum, making forests' future climate, particularly regional and local, challenging to predict. Further, uncertainty is produced by the ecological trends which connect forest distribution and productivity to climate change. Most of the research concentrated on a timeframe that is impossible to understand as the only consequence of climate change. The principal challenge to the interpretation of such findings is the unpredictability of future climate projections. Thus, inventories of long-term vegetation data are indispensable for effectively tracing climate change impacts on the forest. The ecosystem services of forests differ with the composition of site-specific species, influenced by forest governance. A thorough understanding of forest dynamics and their driving factors, either climate change or anthropogenic activities, can lead to forest management strategies. With vast ecological uncertainty and worldwide geological uncertainty, more research and evaluations are needed in the present context, including threats and potential opportunities in likely climate change scenarios. It is important to remember that additional research activities are required for long-term planning to improve forest products and services to meet the know-how gap. This may help in reducing livelihood vulnerability.

3. The Adaptive Capacity and Strategies of the Forest and Dependent Communities

Despite the realization about resilience and adaptive capacity, wide knowledge gaps still exist due to their complex nature and dynamic ecosystem functioning. Resilience, adaptation and vulnerability are found to be related to each other. The conversion of forest land and population dynamics have contributed enormously in shaping the existing patterns of forest distribution across the world [30]. Adapting forest management to climate change entails monitoring and forecasting changes to mitigate adverse impacts or maximize potential benefits [12]. In addition, forest vulnerability and ecological resilience research have significant implications for regeneration and sustainable forest management [61]. Although forest ecosystems are naturally robust, many species and ecosystems have adapted to historically changing climatic settings. Still, the extent and rate of future change may exceed the potential adaptive capacity of forest dynamics. Forest disturbances can affect forest composition and structure, which has ramifications for forest functionality and resistance. Hence, there is an urgent need to prevent and reduce the likely upcoming declines in forested areas to increase individual species adaptation. Forest vulnerability assessments are thus critical for determining which species are at risk due to climate change.

Previous literature has discussed the management theories relating to how local communities adapt to the changes occurring in forest ecosystems conceptually. However, Seidl and Lexer [62] have remarked on the prevalence of discontinuity in the policy initiatives that have been designed and enforced to improve the forest's adaptive capacity. Well-managed forest will considerably minimize local communities' climate change vulnerability. Societies that are directly or indirectly dependent on certain forms of forest typically find ways of adapting to current and potential climatic threats, as forests supply a broader array of ecosystems in different stressed scenarios. Therefore, forest-dependent community adaptation assumes significance, particularly in developing nations. Several options for adaptation may include community awareness, forest fire prevention, forest conservation, and livelihood diversification. However, forest and dependent communities still face several social, economic, political, and environmental problems. Policy interventions which combine adaptation with coping are non-efficient; instead, they promote temporary short-term changes rather than a permanent solution [63]. Thus, climate change adaptation should be considered a risk management component of a long-term forest management plan [52]. A micro-scale implementation of such an approach would be required for its sustainability.

4. Forest Management and Its Scope

Forests face a kind of disturbance that adversely affects their health and vitality. The uneven distribution of forests leads many different organizations to formulate forest policies and suggestions to enhance forest dynamics worldwide. Promoting regeneration, afforestation, forest stability, and trees' resilience to various kinds of disturbance should be practiced to sustainably preserve forest cover. Oak-dominated broadleaved forests in many parts of the world have been transformed into pine forests, mainly by human activities. These pine forests are more vulnerable to climate changes and should be transformed into mixed forests [64][65]. In some regions, forest managers turn the climatically sensitive forest into a diversified forest by gradually replacing species to enhance the forest's biological diversity. This habitat conversion ultimately enhances the forest's adaptive capacity to a great extent [66][67][68]. There are very few studies concerning fundamental research into climate change vulnerability and extinction of flora, posing a great challenge for forestry managers aiming for long-term adaptation measures. Furthermore, there is a severe lack of clear scientific information regarding forest species' response to climate change. Therefore, local indigenous communities' expertise should be promoted and integrated to design solutions for climate change adaptation and reduce climate change impact on forest environments. Community forest management may play an essential part in the sustainable management of forests under the climate change scenario.

Local dependent communities protect various forest regions; however, they are not well-recognized and well-documented, risking the loss of political and financial support. In many countries, stakeholder involvement in the forest has resulted in the restoration of endemic flora and fauna [62][69]. Indigenous communities also advocate the use of trees and forestry tools in various land management scenarios which encourages them to participate in community-based land conservation activities, carbon sequestration programmers and other CFUGs, for example, REDD+ initiatives or CDM (Clean Development Mechanism) [30][70]. Such community participation will help forests to meet the indeterminate effects of climate change by preserving species that have become critically endangered or face risks. This kind of forest management improves forests' ecological variability, thus enhancing their capacity to adapt. Substantial community efforts to sustainable forest resource management guarantee improved natural resources, controls on indiscriminate and non-scientific degradation, and poverty reduction among several vulnerable communities. Further, combining knowledge of system vulnerabilities is imperative for devising management strategies involving risk and uncertainty to promote long-term sustainability [71].

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